SILICON LIGHT EMITTING DIODE, SILICON OPTICAL TRANSISTOR, SILICON LASER AND ITS MANUFACTURING METHOD

BACKGROUND OF THE INVENTION

[0001] The present application claims priority from Japanese application JP-A-2006-120065 filed on Apr. 25, 2006, the content of which is hereby incorporated by reference into this application.

FIELD OF THE INVENTION

[0002] The present invention relates to a light-emitting device using silicon. More particularly, it relates to a high-luminance light-emitting diode, an optical transistor whose light intensity/wavelength is controllable with the gate voltage, a silicon laser, and their manufacturing method.

DESCRIPTION OF THE RELATED ART

[0003] In broadband networks which support the Internet industry, optical communications are employed. Lasers using III-V or II-VI compound semiconductors are used for light transmission/reception in the optical communications.

[0004] Although various types of structures have been advocated for the compound semiconductor lasers, the most common one is the double hetero structure. The double hetero structure is a structure such that, using two types of different compound semiconductors, the compound semiconductor with a smaller bandgap is sandwiched between the compound semiconductors with larger bandgaps. When fabricating the double hetero structure, these respective compound semiconductors, i.e., the n-type compound semiconductor, the none doped i-type compound semiconductor, and the p-type compound semiconductor, are epitaxially grown continuously on a substrate, thereby being multi-layered in the vertical direction. At this time, there is a need of paying attention to the band structure of the none doped i-type compound semiconductor sandwiched in between. This means that the following conditions are important: The bandgap of the i-type compound semiconductor is smaller than the ones of the n-type and p-type compound semiconductors, and conduction-band level of the i-type semiconductor is lower than conduction-band level of the n-type semiconductor, and valence-band level of the i-type semiconductor is higher than valence-band level of the p-type semiconductor. Namely, the structure is formed so that both electrons and holes will be confined into the i-type region. On account of this, the electrons and the holes become likely to stay in the same i-type region. Accordingly, the probability enhances that the electrons and the holes collide with each other thus to be subjected to pair annihilations. As a result, it becomes possible to increase the light-emission efficiency. Also, the refractive index tends to become larger as the bandgap becomes smaller. Consequently, it turns out that the light as well will be confined into the i-type compound semiconductor by selecting materials where the refractive index of the i-type compound semiconductor is smaller than the ones of the n-type and p-type compound semiconductors. Then, the confined light effectively stimulates recombination of the electrons and the holes which form population inversion, thereby bringing about implementation of laser oscillation.

[0005] Based on the optical communications using the compound semiconductors which emit light effectively in this way, long-distance information communications are currently performed in an instantaneous manner and in large amounts. Namely, at present, information processing and storage are performed on the silicon-based LSIs; whereas information transmission is performed with the compound-semiconductor-based lasers.

[0006] If silicon could be caused to emit light with a high efficiency, both the electronic devices and the light-emitting devices could be integrated on a silicon chip. This prospect promises tremendous industrial values. Accordingly, researches for permitting silicon to emit light are being performed energetically on a large scale.

[0007] However, it is difficult to cause silicon to emit light with a high efficiency, because silicon has the indirect-transition band structure. The indirect-transition band structure refers to a band structure where either of the momentum at which energy in the conduction band becomes the minimum and the momentum at which energy in the valence band becomes the minimum is not equal to zero. In the case of silicon, although the minimum energy point in the valence band is the Γ point at which the momentum becomes equal to zero, the minimum energy point in the conduction band is not at the Γ point, but is positioned between the Γ point and the X point. More concretely, defining $k_0=0.85*\pi/a$ where a denotes the lattice constant, the minimum energy point in the conduction band exists in a degenerated manner over six points of $(0, 0, \pm k_0)$, $(0, \pm k_0, 0)$, and $(\pm k_0, 0, 0)$ FIG. **1**A illustrates this degenerated manner of existence.

[0008] In contrast thereto, many of the compound semiconductors are referred to as direct-transition semiconductors. The reason for this is that, in each of them, the minimum energy point is positioned at the Γ point both in the conduction band and in the valence band.

[0009] Next, the explanation will be given below concerning why the light-emission efficiency is bad in the indirect-transition semiconductors, and the light-emission efficiency is good in the direct-transition semiconductors.

[0010] As described above, causing a semiconductor device to emit light requires that an electron and a hole collide with each other thus to be subjected to pair annihilation, and that the difference in energy therebetween be extracted as light. At this time, both of the conservation law of energy and the conservation law of momentum must be satisfied. The electron has its energy level within the conduction band, while the hole has the energy level of a portion at which the electron is absent within the valence band. The difference between both of the energy levels becomes equal to the energy that the light has. Also, wavelength of the light comes to differ depending on the energy thereof. As a result, it turns out that the energy difference between the conduction band and the valence band, i.e., magnitude of the bandgap therebetween, determines the wavelength of the light, i.e., color of the light. Considering the energy aspect in this way, no specific difficulty can be found out in the establishment of the conservation law of energy.

[0011] On the other hand, the momentum must also be conserved, because the collision phenomenon of the electron and the hole is related with the light emission. According to quantum mechanics, which is the physical law that governs the microscopic world, an electron, a hole, and a photon (i.e., quantum of light) are all waves as well as particles, but are scattered as the particles. As a result, the conservation law of momentum is established. The momentum is, qualitatively, a scale of quantifying with about how much impetus a particle